MEASUREMENT OF HUMAN PERFORMANCE FOR FUTURE COMBAT SYSTEMS COMMAND AND CONTROL

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ABSTRACT

Historically, Army acquisition has had difficulty conducting an adequate early assessment of the human dimension in system performance. Proactive research on human performance, however, is vital to achieving the unprecedented alliance of humans and machines anticipated with Future Combat Systems (FCS). This paper summarizes research methods and findings across four exploratory experiments focused on the command group of a small combined arms unit composed primarily of unmanned air and ground vehicles. Results are based on highly detailed objective measures of verbal and human-computer interaction and an array of subjective measures from expert and novice participants. Findings underscore potential problems in training and workload with FCS, and potential solutions through user-based involvement and proactive research to ensure technology complements human performance.

1. INTRODUCTION

The U. S. Army's transformation to Future Combat Systems (FCS) anticipates an extraordinary alliance of humans and machines. Examples include humans working with "bots" to process information and make decisions, and working with robots to move, see, and strike (Department of the Army, 2003). Creating an FCS alliance that actually improves, and does not impede, battle command is a human systems integration challenge.

A fundamental lesson from modern warfare is that the insertion of technology burdens and stresses the force (Cordesman & Wagner, 1996). The burden on Soldiers with new technology is attributed less to technology per se, than to inflated expectations *about* technology.

New technologies may help commanders visualize and describe the operation and direct subordinates to mission accomplishment. However, many command and control (C^2) tasks are too complex and important to assign to machines. How to best allocate human-machine tasks and functions for future command groups is a key concern in Army transformation.

The Army learns by doing. The research reported here exemplifies the Army's effort to proactively explore C^2 concepts and address human system integration issues for the Future Force. The FCS C^2 research program, currently called Multi-Cell and Dismounted Command and Control (MC&D C^2), conducted an incremental series of command-in-the-loop experiments at Fort Monmouth, NJ from October 2001 to March 2003.

Program leads were the Defense Advanced Research Projects Agency (DARPA) and the U.S. Army Communications–Electronics Command (CECOM) Research, Development and Engineering Center (RDEC). As a program partner, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) measured human performance to improve human system integration and training, and to support the Science and Technology Objective (STO) titled "Methods and Measures of Commander-Centric Training."

The purpose of the FCS C^2 research was to explore the hypothesis that digitization of current battlefield operating systems enables a *new* approach to command and control. To test this hypothesis, the FCS C^2 program created a research environment to assess command group performance in a notional FCS small combined arms unit, called the Unit Cell. Figure 1 depicts the manned and robotic elements of the Unit Cell organization used in Experiments 1-4, including the surrogate C^2 vehicle occupied by the command group participants. The command group directly controlled 16 air and ground vehicle systems, 13 of which were unmanned platforms.

The four primary participants in the command group were active-duty U. S. Army lieutenant colonels who served as Commander, Information Manager, Effects Manager, and Battle Space Manager. Their four C^2 workstations provided a common picture of the battlefield and allowed them to command and control their Unit Cell assets. Through the C^2 workstations linked to Distributed Interactive Simulation (DIS), the command group participants interacted with virtually simulated elements of the friendly force, the threat force, and civilian/ noncombatant entities during the conduct of experimental missions.

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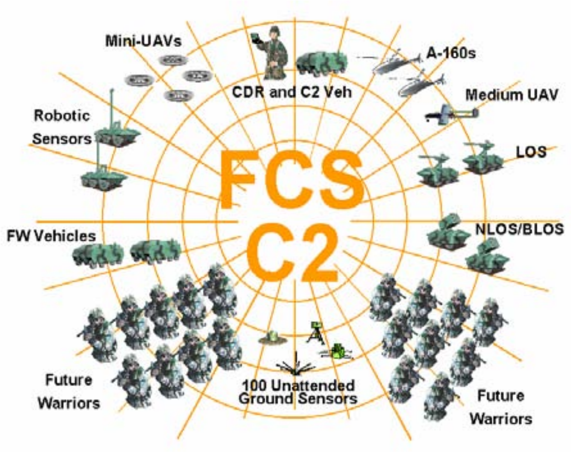

Figure 1. Organization of the Unit Cell

To explore new approaches to command and control, the research environment and the command group's operational requirements were expanded and refined as the experiments progressed. New features were added to the C^2 prototype and older features were refined or abandoned, based on lessons learned in prior experiments. These technical refinements often resulted in changes by the command group in the allocation of tasks and functions.

By design, the operational requirements on the command group and the Unit Cell escalated across experiments, as bulleted below. Experiment 1 only addressed the ability of the Unit Cell to See/Move, namely to maneuver its elements in order to see and not be seen. By Experiment 4, the mission of the Unit Cell and capabilities of the C^2 prototype progressed to Improved See/Move/Strike and Sustain operations.

- Exp 1 — Dec 01 — See/Move (with limited Strike).
- Exp 2 — May 02 — Improved See/Move and Strike.
- Exp 3 — Sep 02 — Improved See/Move/Strike.
- Exp 4 — Mar 03 — Improved See/Move/Strike and Sustain.

An additional experiment with Army Cadets called the Summer Experiment was conducted in August 2002 that resulted in a comparison of novice versus expert command group performance.

In support of the FCS C^2 effort, ARI developed and applied a set of human performance measurement methods to systematically describe and quantify the behavior of the command group. This document provides a brief overview of the methods, results, and conclusions of the ARI effort.

More complete documentation is in ARI's Interim Reports on each experiment available from the Program Manager (PM) MC&D C^2 and ARI reports (Lickteig, Sanders, Durlach, Lussier, & Carnahan, 2004a; Lickteig, Sanders, Durlach, & Carnahan, 2004b).

2. METHOD

For each two-week experiment, the command group typically conducted 10-12 Deliberate Attack missions called experimental "runs" in a mock-up C^2 vehicle, shown in Figure 2. Each experimental run required approximately 2-3 hours for completion including the planning and execution phase, resulting in two runs per day. At the end of each day, a team of subject matter experts led an After Action Review (AAR) of the day's runs to review operational, technical, and human performance issues.

Figure 2. Command group participants in a surrogate command and control (C^2) vehicle.

Table 1 depicts the basic experimental schedule for the FCS C^2 Experiments 1-4. Variations in schedule were relatively moderate for exploratory research and mainly due to technical problems during Experiments 1 and 2. The first three days of each experiment were dedicated to training, and the seven remaining days to experimental runs. Training on days 1-2 addressed participants' individual skills with the C^2 prototype system. Training was intentionally not duty position specific, but rather designed to provide cross-duty skills across the command group. Collective training on day 3 took place in the C^2 vehicle and used virtual simulation to support run rehearsal.

Table 1. Basic Schedule For Experiments 1-4.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
AM	Training			Run 1	Run 3	Run 5	Run 7	Run 9	Run 11	Final AAR
PM	Training			Run 2	Run 4	Run 6	Run 8	Run 10	Run 12	

2.1 Experimental Design

A key feature of the experimental design was a *deliberate practice* approach in which a stable group of experienced officers repeatedly executed a similar mission on similar terrain with similar assets. The use of deliberate practice helped insure results were based on a proficient command group. A common mistake, especially when experimental systems differ radically from current systems, is testing with unfamiliar troops who receive last-minute training. In such cases, training deficiencies may overshadow and confound all other performance considerations.

A second design feature involved systematically varying *run complexity* levels as a function of METT-TC (Mission, Enemy, Terrain, Troops, Time and Civilians). Three levels of run complexity (Medium, High, and Too High) were developed by increasing enemy force activity and size, restricting a key friendly asset, and inserting civilians on the battlefield. Levels of complexity were randomly assigned to runs during Experiments 1-3, however, all runs were conducted at the High level during Experiment 4 to establish "baseline" performance indicators for future efforts.

Run complexity was used to identify how changes in the unit's operational conditions affected command group performance, and to gauge the performance limits of the proposed Unit Cell organization. The complexity of the mission was expected to change workload, performance, and human-system integration requirements.

2.2 Interface Design

Figure 3 provides a sample depiction from one of the two C^2 displays at each participant workstation. The dual displays were identical and allowed participants to independently configure each display to support C^2 requirements by position and user preferences. Each display provided a common picture of the battlefield situation and control over all the automated and interdependent systems in the Unit Cell.

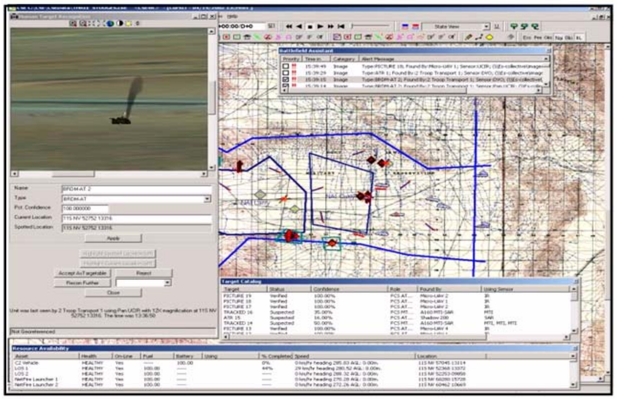

Figure 3. A sample view of a C^2 display with the sensor Image Viewer opened at the left.

2.3 Human Performance Measures

Four types of human performance measures were developed, iteratively refined, and repeatedly used during Experiments 1-4:

- Verbal interaction measures based on audio recordings of the exercises examined the command group's verbal communications.
- Human-Computer Interaction (HCI) measures based on video recordings of the exercises examined the command group's interactions with their prototype C^2 systems.
- Subjective measures included surveys and questionnaires soliciting ratings and comments from the command group participants.
- Automated measures were designed, and a few developed and validated, to automatically record the command group's interactions with the prototype C^2 systems during experimental runs.

2.4 Evaluation Framework

The human performance research methods used an evaluation framework based on a functional analysis of the participants' command group performance. The set of C^2 functions used to analyze verbal and human-computer interactions were:

- Plan: Develop, assess, and modify plans including tasking for unmanned air/ground assets in response to changing events.
- See: Control/interpret input from a set of manned/ unmanned networked sensors to maintain accurate battlefield "picture."
- Move: Control movement and activity of manned/ unmanned assets.
- Strike: Control manual/automated networked fires.
- BDA: Control/interpret input from a set of manned/ unmanned networked sensors for information collection and battle damage assessment (BDA).

3. RESULTS

A small sample of the results on human performance across Experiments 1-4 is provided in this section.

3.1 Verbal Communications Results

Verbal interaction by the command group was an almost continuous activity. Breaks in command group verbalization, or silent time, averaged only 7% during the execution phase of a run. The finding that verbalization by the command group occurred 93% of the time during run execution is noteworthy. The pattern of steady conversation occurred despite participants' common access to a visually rich and timely depiction of the battlefield situation on their C^2 displays. Figure 4 illustrates the dominant role of the Commander in the command group's discussions across the four experiments.

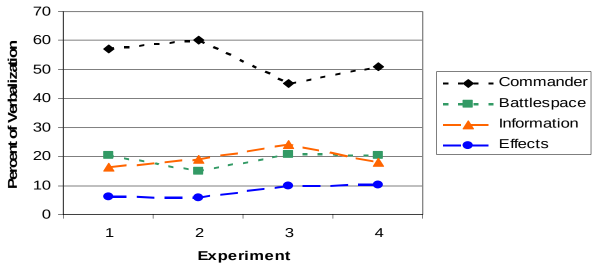

Figure 4. Percent of verbalization by duty position.

The largest percentage, about 30%, of verbalizations during run execution supported the See Function, as shown in Figure 5. Verbal discussion primarily supported collection and interpretation of data from multiple ground and air sensors to construct an accurate picture of the battlefield. Nearly 15% of all discussion was devoted to the closely related function of battle damage assessment (BDA).

Figure 5. Percent of verbalization by function.

In addition to duty position and C^2 function, the communications within the command group and with surrogate higher echelons were analyzed by:

- Source: Within Cell, Cell-Higher, Higher-Higher
- Factor: Mission, Enemy, Terrain, Troops, Time, & Civilians
- Type: Share, Act, Direct, Ask, Process, and Decide
- System: Platform break-out of FCS air/ground assets.

3.2 Human-Computer Interaction (HCI) Results

The coding categories developed for HCI analysis were based on the C^2 functions of Plan, See, Move and Strike. The categories and codes used to assess HCI were revised and expanded over the course of experiments as new features were added to the C^2 prototype. For example, thirteen (13) new features were introduced for Experiment 3, such as automated fires based on sensor-shooter links and automated route generation for unmanned vehicles.

HCI analysis also identified and related sub-functions and interactions to the primary C^2 functions, as depicted in Figure 6. For Experiments 2-4 respectively, the number of HCI categories expanded from 53 to 84 to 97

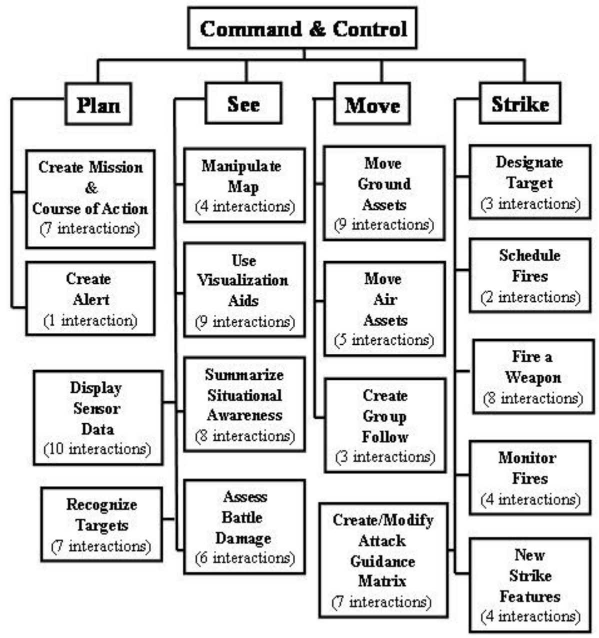

Figure 6. HCI coding categories by Experiment 4.

different types of human interaction with the C^2 prototype. (No HCI analysis of Experiment 1 was possible due to low-resolution video recordings.)

Figure 7 provides a summary look at HCI frequency during typical 90-minute run execution phases by duty position and experiment. The frequency of interaction by the three Battle Managers during run execution was substantially higher than the Commander's interaction. Peak performance by the Battle Managers during more intense run segments was 9-12 interactions per minute.

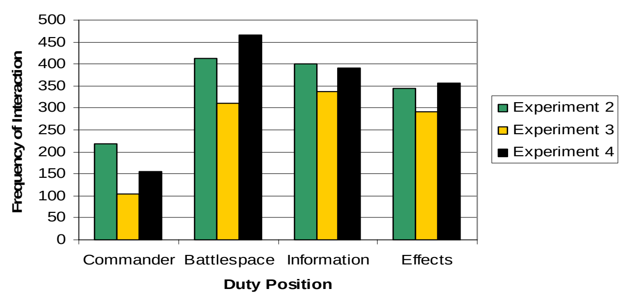

Figure 7. Frequency of interaction during run execution by duty position and experiment.

Figure 8 provides a more detailed look at HCI results by C^2 function, duty position, and display during the *execution* phase of a typical run. The 1,044 interactions summarized in Figure 8 related to the following C^2 functions: Move (5%), See (75%), and Strike (20%). By comparison, the 499 interactions during the *planning* phase of the same run were related to the following functions: Plan (36%), Move (11%), See (51%), and Strike (2%).

Figure 8 also illustrates how each participant elected to perform their interactions by display. Display preferences were clearly not uniform: left display used primarily by the Effects Manager, right display by the Battlespace Manager, and fairly balanced left and right display use by the Commander and the Information Manager. Such results raise research questions about interface design, including user needs and preferences, that future efforts might address to improve human system integration.

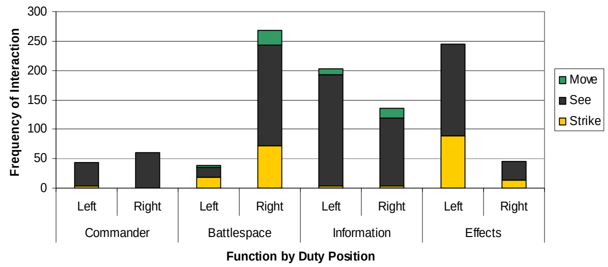

Figure 8. Frequency of interaction by function, duty position, and display during a run execution phase.

3.3 Subjective Results

Subjective results addressed many research issues including workload, human performance, system performance, and training. Workload was a key concern given the FCS goal of reducing the size of the command group for a small unit with manned and predominantly robotic elements.

Figure 9 provides a comparison of each participant's average rating of overall workload across complexity levels by experiment and duty position. The results indicate that participants experienced moderate to high levels of workload with the highest workload reported by the Information Manager.

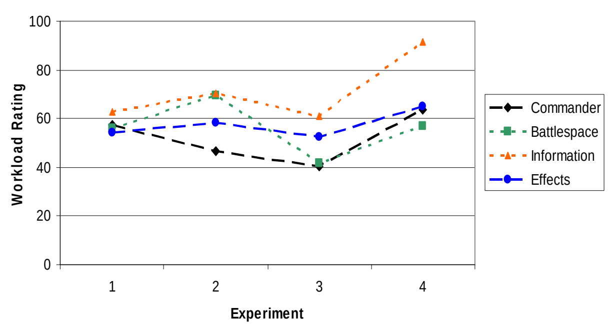

Figure 9. Overall workload ratings by duty position and experiment (0 = Very Low, 100 = Very High).

Performance success is always a key concern. Participant ratings of performance success during run execution declined sharply at the Too High level of complexity, as shown in Figure 10 from Experiment 3. The Information Manager's low ratings, for example, reflect human system integration issues in controlling unmanned aerial vehicles (UAVs) and in analyzing more sensor images in the Too High condition.

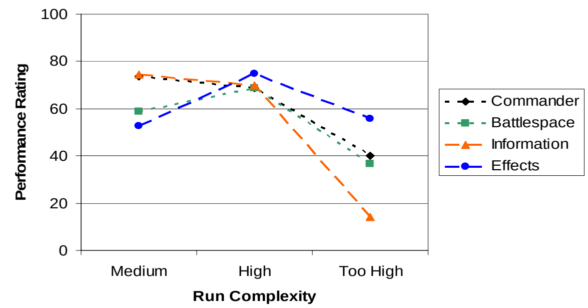

Figure 10. Mean performance success ratings by run complexity and duty position during a typical run's execution phase (0 = Failure, 100 = Perfect).

System performance ratings by participants assessed the effectiveness of key C^2 prototype features added or modified across experiments. Figure 11 indicates how participants rated the thirteen (13) new features added for Experiment 3. Overall, most of the new features received positive ratings. However, ratings were "Ineffective" to "Neutral" on the Human Target Recognition (HTR) Viewer and on a Group Tasking feature that was expected to help move robotic ground vehicles. The questionnaires also captured participants' comments which were used to add, drop, or refine C^2 features for future experiments.

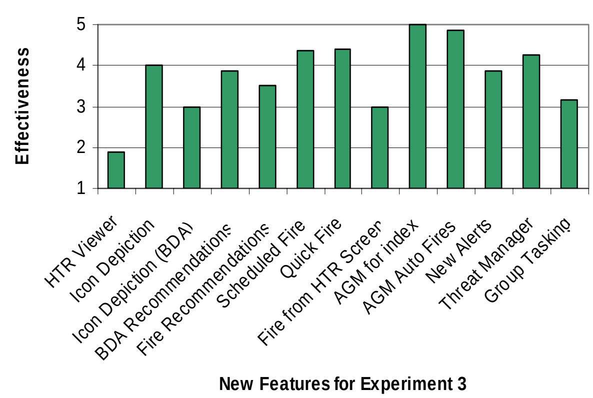

Figure 11. Ratings of new feature effectiveness
(1 = Very Ineffective, 5 = Very Effective).

Results on training were based on participant feedback on training surveys and author observations. During the course of experiments, the individual training received by the command group participants improved substantially. Improvements included the development of a User's Manual to support training and performance, and the addition of a dedicated trainer. Shortcomings in the training, however, were observed and documented, particularly in the area of collective training across the command group.

Participants were more critical of the training after performing. For example, after Experiment 4 participants expressed more concerns about training content and time after they had completed the experimental runs. Prior to the experimental runs, and immediately after training, their assessment of the training was more favorable. This finding seems an important reminder that often “you don’t know what you don’t know” until you try to do the job.

Even after Experiment 4, the participants who had completed 40+ runs across experiments expressed strong concerns about the training requirement and their ability to exploit Unit Cell capabilities. Overall, the training results indicated that high levels of tactical and technical expertise will be required by command groups equipped with the automated and interdependent systems expected with FCS.

3.4 Automated Measures

Automated measures of human-computer interaction are required to provide efficient and effective measures of command and control performance for training and evaluation (Department of the Army, 2003). The manual analysis of participants’ human-computer interactions for FCS C^2 underscored this requirement. Identifying and tabulating the 1,500+ interactions that typically occurred during a run’s planning and execution phases required about 16 analyst workdays.

A set of 23 automated measures were identified by ARI to capture command group interactions with the C^2 prototypes. A goal was to validate the automated data obtained against ARI’s manually derived data on corresponding HCI measures. However, only 3 of the 23 automated measures requested by ARI were actually developed, and only 2 of those 3 measures were successfully validated. This result highlights the need for “command emphasis” to meet the FCS requirement for automated performance assessment.

3.5 Novice Versus Expert Performance

A comparison of novice versus expert command groups was based on cadet performance during the Summer Experiment versus the lieutenant colonel performance during Experiments 2 and 3. Applying the same measurement approach to cadets’ command group performance resulted in clear and important differences between the two groups (Carnahan, Lickteig, Sanders, & Durlach, 2004). Findings that seem likely to reflect true novice-expert differences included:

- Novices spent more time in silence, less time collaborating.
- Novices talked more about firing, less about seeing.
- Novices talked more about own troops, less about enemy.
- Novices talked more about enemy location, less about enemy size, type, and disposition.
- Novices performed fewer computer interactions to recognize and identify targets.
- Novices performed more computer interactions to assess battle damage.

These results are consistent with other findings in the tactical domain in which novices demonstrate greater concern with friendly versus enemy activities and view the enemy in a more one-dimensional fashion (Strater, Endsley, Pleban & Matthews, 2000). The novice group seemed to approach their command and control roles with a hasty “find and kill” mindset, not unlike a video game. In contrast, the relatively expert command group deliberately strived to build an accurate and complete account and understanding of the battlefield situation.

4. CONCLUSIONS

Conclusions underscore potential problems in training and workload with FCS, and potential solutions through user-based involvement and proactive research to ensure technology complements human performance.

4.1 Workload

Human performance findings from the FCS C^2 Experiments 1-4 indicated moderate to high levels of workload for the participants. Overall, the findings suggest that workload may be a serious concern for future command groups in small FCS units in more complex situations. Objective data confirmed that participants were heavily engaged in verbal and human-computer interaction during the execution of more complex runs and more intense run segments. Subjective data emphasized the potentially negative impact of workload based on participants’ low to moderate ratings of their performance success in more complex runs.

Automation can reduce workload, but also increase it. For Experiment 3, an automated audit trail on sensor images was introduced that indicated if, when, and by whom each image had been opened and viewed. The audit trail helped reduce the number of same images reviewed in Experiment 2 versus Experiment 3 from 62% to 16%. A conclusion after Experiment three, was that the decreased workload observed, based on objective HCI data and subjective responses, was due to the array of new and increasingly automated features added to the C^2 prototype for Experiment 3.

However, increases in HCI frequency (Figure 7) and perceived workload (Figure 9) occurred in Experiment 4 despite more automated features and a more experienced command group. Perhaps, *programmatic* expectations about better baseline performance levels, including requests to the command group for faster run/mission completion, raised performance requirements. Similar increases in workload based on expectations about doing "more with less" through technology are common in the military (Cordesman & Wagner, 1996).

4.2 Training

FCS command groups will require exceptional levels of tactical and technical expertise. Command groups with robotic elements must reformulate battle commands into computer commands. Traditionally, succinct military communications like commander's intent and guidance entail many implied tasks for manned systems. In the future, communications with unmanned systems will require more explicit and precise specification in computer-mediated and –dictated formats.

Technical, and even tactical, expertise may also quickly degrade as C^2 and FCS systems change rapidly in response to changes in technology and operational requirements.

Understanding the limits and strengths of notional FCS systems and the C^2 system that controlled them was a severe challenge. The participants in the command group contributed heavily to the design of the C^2 prototype, conducted numerous runs across experiments, and had higher rank and more operational experience than expected for future FCS small-unit leaders. Despite these advantages, the command group continued to report difficulty in understanding the input requirements and operational consequences for highly automated and interrelated Plan, See, Move, and Strike functions across the four experiments.

The participants' parting responses on training, after their fourth experiment and 40+ runs, underscored the training challenge for future command groups in units with the automated and interdependent systems anticipated for FCS:

- Need more hands-on in tactical scenarios or vignettes, less lecture. Putting the lesson in a tactical situation really lends credence to the function you are teaching and demonstrates why you want to learn it and how it is best employed.
- Training should be more dedicated to actual employment techniques. We could have used more time integrating as a team.
- We get more functional every run, what we need are a couple of runs designed for us, not to be critiqued (i.e., in AAR), but for us to re-establish SOPs…. Not an easy task....

Training is the glue that will hold FCS and the Future Force together. Conclusions by ARI stress the need for three basic but far-reaching improvements in the training for FCS, particularly command groups:

- Develop progressive and simulation-based training exercises directed at *individual* technical and tactical skills, especially user input requirements for, and the consequences of, automated functions.
- Develop a parallel set of collective training exercises for *intra*-unit technical and tactical skills.
- Develop a parallel set of multi-echelon, distributed training exercises for *cross*-unit technical and tactical skills.

4.3 Warfighter Involvement

The C^2 interface is increasingly the primary locus, or means, of interaction between Soldiers and systems. Developing an optimal interface requires sustained and intense warfighter involvement.

A distinctive hallmark of the FCS C^2 program is the commitment by the same participants over two years and four experiments to use and refine a prototype C^2 system. The program continues to develop and refine a cutting-edge interface to command and control an FCS equipped force. Key aspects of the program's prototype C^2 system and interface include:

- Value based on military experts' sustained use.
- Viable interface to networked/unmanned systems.
- Common interface to manned/unmanned systems.

4.4 Proactive Research

Historically, Army acquisition research has had difficulty conducting an adequate early assessment of the human dimension in system performance. This human performance issue is especially critical for FCS because the empowerment of the commander through advanced C^2 systems is at the heart of the FCS concept.

Moreover, the revolutionary nature of the Army's transformation embodied in the FCS acquisition program increases the risk of relying exclusively on traditional assessment methods such as C^2 hardware and software component tests, or the outcomes of simulation without Soldiers-in-the-loop.

The FCS C^2 program, now expanded to MC&D C^2, exemplifies the proactive research on human performance that is essential to forging the human-machine alliance required by FCS. ARI's methods and results on human performance provide reliable and empirical data for important and timely decisions on training, materiel, manpower, and personnel.

The human performance findings summarized here were readily transitioned to FCS acquisition efforts, in part due to DARPA's dual roles in FCS simulation and acquisition. The FCS Integrated Product Team for Training is using the human performance findings in their plans and designs. Feedback based on the findings helped shape the C^2 prototype showcased in the Capstone Demonstration of C^2 systems prior to FCS Milestone B. The analysis of command group tasks and human-computer interactions by ARI was provided to the Lead System Integration Package 27 Vendors for FCS.

In closing, two additional conclusions are stressed. The ultimate value of a C^2 research and development program is determined as much by the investment in training and evaluation, as investment in simulation. The ultimate value of a C^2 system is determined not so much by technology, but by shaping technology to complement human performance.

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